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Digital Technology in Architecture, Engineering and Construction (AEC) Industry: Research trend and Practical Status towards Construction 4.0

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ABSTRACT

Construction 4.0 represents the exploration of new technologies in the architecture, engineering and construction (AEC) industry. The development of digital technologies is rapid and the adoption of them significantly impacts construction projects, for example leading to a reduction in change orders, better decision making, and improvements in quality of work. However, stakeholders may find it challenging to determine the promising technologies within the context of the AEC industry. This paper presents an exploratory study to investigate the potentially applicable technologies and their research and practice trends in the AEC industry. A scoping review was the method utilized to perform a quantitative analysis of over five thousand journals papers published from 2010 onwards based on two academic databases (Scopus and CNKI). The results present the top 10 construction 4.0 technologies, including building information modelling (BIM), artificial intelligence (AI), 3D printing, machine learning, internet of things (IoT), geographic information systems (GIS), virtual reality (VR), big data, robotics and augmented reality (AR). Subsequently, 145 industry professionals were invited to select the most used construction 4.0 technologies in their projects via a questionnaire survey. Mobile devices, BIM and Digital signature are mostly adopted on-site. The findings of this study can enhance the awareness of stakeholders towards construction 4.0 technologies and may help them make better decisions in selecting and implementing the promising technologies.

KEYWORDS: BIM, Digital technology, Technology adoption, Questionnaire, AEC industry

INTRODUCTION AND BACKGROUND

Many industries will change as a result of the technical development towards the fourth industrial revolution. Digital technologies are explored within Industry 4.0 by the manufacturing industry to find beneficial effects and improve productivity. Construction 4.0 is the equivalent of exploring new technologies in the architecture, engineering, and construction (AEC) industry (Craveiroa et al. 2019). The AEC industry is an important contributor to China's national economy. In 2020, the total value of the industry reached 26.4 trillion RMB, with an increase of 6.2% over the previous year, which accounted for 7.2% of Gross Domestic Product (GDP)

(National Bureau of Statistics 2021). However, the number of practitioners has decreased and the expense of the construction workforce has increased for two consecutive years in the industry (CCIA 2021). Therefore, the Chinese government proposed to speed up the digital transformation from the traditional paper-based approach in the AEC industry in the country's fourteenth five-year plan, in order to mitigate the issues such as loss of labour, carbon dioxide emission and cost overrun. At the same time, digital devices, methods, and systems (also known as digital technologies) have been developed vigorously, which provide strong support for the digital transformation of new construction projects. By adopting digital technologies, enormous opportunities could be introduced for enhancing the effectiveness and quality of construction processes and creating business innovation. For example, the AEC industry is experiencing an unprecedented reform of tools and methodology because of the incorporation of building information modelling (BIM), integrated project management (IPD) and lean construction. Also, the productivity of the AEC industry could be greatly improved if new technologies are leveraged more effectively. Significant managerial and technological advancements have been observed due to the technology application in the AEC industry (Sepasgozar et al. 2018).

Nevertheless, many studies have indicated that the AEC industry is reluctant to implement emerging technologies, which shows lower levels of technology maturity than other industries such as manufacturing, electronics and aviation (Pärn and Edwards 2017). Compared to other industries, Oesterreich and Teuteberg (2016) stated that the AEC industry is more difficult to manage and integrate new technologies, because construction projects are complex, requiring individual undertakings and a high level of professional knowledge. They also concluded that some challenges and problems should be taken into account before the digital transformation of the industry, such as organizational and process changes, resistance to technological change, hesitation to adopt technologies, and others. For instance, a large amount of small and medium-sized enterprises (SMEs) hesitated to invest in new technologies due to the low awareness of the benefits and the trends of the technology application. At present, it is impossible and inappropriate to adopt various technologies in companies due to the large investments. It is worthwhile to identify the digital technologies that have big potential for the current and future AEC industry to improve the awareness of these technologies.

Thus, this paper aims to fill a gap in literature by providing an overview of the current research and practical trend of digital technologies in the AEC industry. In order to achieve this aim, the following objectives arise: (1) To identify digital technologies that are currently associated with the concept of construction 4.0; (2) to investigate the research trend of these technologies in the AEC industry; (3) to point out the current status of these technologies implemented in the Chinese AEC industry.

Based on these questions, the findings of this study will enhance the awareness of researchers, government policymakers, and industry stakeholders of current promising technologies and direct them towards digital transformation.

RESEARCH METHODOLOGY

This study employed literature and industrial questionnaire survey to provide a comprehensive insight into the research trend and current application status of digital

technologies in the AEC industry. The process for this study is illustrated in Figure 1.

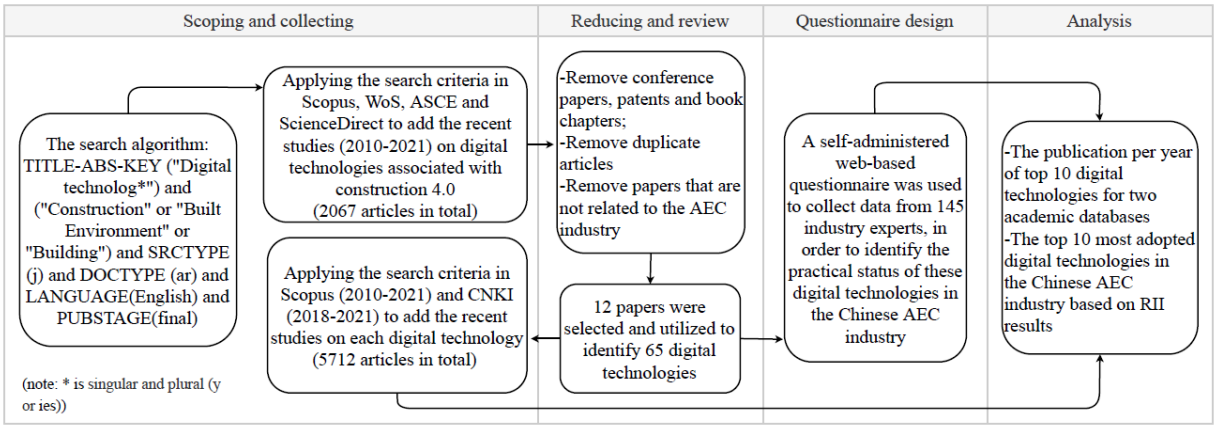

Figure 1 Research design

State of the art

The technological stream constitutes a significant research field concerning digital transformation. Peculiar technologies can lead to important improvements in technique and organization. Nevertheless, there are some inconsistencies of technologies list among the different domains. In order to identify the current and potential technologies used in the AEC industry, a preliminary search of existing literature was conducted. Multiple databases, including Scopus, Web of Science, and specific publishers such as the American Society of Civil Engineers (ASCE) were employed to search for and identify useful publications related to the digital technologies in the industry. The scoping review technique of the Literature-Based Discovery (LBD) approach (Levac, Colquhoun and O'Brien 2010) was adopted at this stage, suitable for overviews of key concepts and research gaps of emerging areas. Following the scoping review steps derived from the framework, relevant studies were selected. Twelve full-text papers were included in the final review after data characterization of the searched journal articles, identifying 65 related technologies.

Analysis of trends in existing research is helpful in identifying popular topics and exploring future research direction. To investigate the number of research articles related to each technology in the field of construction industry, the Scopus database was selected as the basis for this investigation since it has comprehensive coverage of high-quality peer-reviewed articles and the availability of more recent publications (Zhao et al. 2019). In order to identify the latest research trend reported in the literature, the published papers are confined to the last ten years, from 2010 to present (as of 29 April 2021). Two selection criteria were applied to filter the articles: (1) The searched technology is the main research topic employed in the article, this is because some studies only mentioned the technology such as 5G, whilst did not actually investigate 5G in the article; and (2) the application of this technology is related to AEC industry. Table 1 summarizes the frequency of occurrence for the top ten technologies investigated in worldwide journal publications. Due to space limitations, an overview of each specific technology is not possible, the readers are directed to the website (https://www.researchgate.net/publication/354234827_Digital_technologies) for additional information.

Furthermore, to reflect the current research trend of these technologies in China, the core

Chinese journal papers published were also screened based on the same steps. CNKI database was selected as the data source for its wide adoption in China. Firstly, a pilot screening was conducted to search the target papers, showing that a limited number of papers were published from 2010 to 2017, hence, only the papers published after 2018 were counted here. Figure 2 shows the frequency of occurrence for the top ten technologies investigated in the selected Chinese database published from 2018 to present.

Survey instrument

A structured survey questionnaire was designed to investigate the current status of applying the identified technologies on construction site. The survey contained four sections: (1) objectives of the study along with a consent form; (2) demographic background of participants; (3) participant's experience level on the identified technologies; and (4) recommendation of the promising technologies that should be invested in the AEC industry. In terms of section three, the experience level of each technology was rated on a five-point Likert scale from 1 (very low level) to 5 (very high level). The relative importance index (RII) method was employed to calculate the experience level with each technology. This technique is utilized to determine the importance of each indicator compared with others (Metro et al. 2021). The RII equation is presented below:

$$\text{RII} = \frac{\sum W}{A \times N} = \frac{1n_1+2n_2+3n_3+4n_4+5n_5}{5(n_1+n_2+n_3+n_4+n_5)} \qquad (0 \leq \text{RII} \leq 1)$$

Where W is scale weight from 1 to 5, value given to each technology by the respondents, A is highest weight given (=5), and N is total number of respondents.

Concerning the survey sample, the unit of analysis in this survey refers to the employees in the Chinese AEC industry. A Chinese website (https://www.wenjuan.com/) providing online survey services was utilized to create the online questionnaire. Firstly, a pilot testing with five experts from academia and industry was carried out to review the technologies and the readability of the questionnaire. Minor modifications were made in response to the feedback received.

This research is exploratory, hence, a nonprobability purposive sampling technique was employed for this study. Subsequently, the authors distributed 375 online questionnaires via Email, LinkedIn or WeChat (communication software developed by Tencent) to the target respondents. A total of 167 (44%) responses were received and all of them were complete without missing data because of the online survey settings. Then, the repetitive responses with the same Internet Protocol (IP) address were eliminated, and invalid responses with the same rating for the Likert chart were discarded. Consequently, 145 valid samples were utilized for further analysis.

RESULTS AND DISCUSSIONS

State of the art – publication growth trends

This study identified sixty-five digital technologies that could be implemented in the construction industry. Among them, Table 1 presents the top ten technologies that have been studied over the past decade, including BIM, Artificial Intelligence (AI), 3D Printing, Machine Learning, Internet of Things (IoT), Geographic Information system (GIS), Virtual Reality (VR),

Big Data, Robotics and Augmented Reality (AR). Each of them is briefly introduced below.

Table 1. Frequency of occurrence for the top ten digital technologies (Scopus)

Sequence number	Technology	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
1	BIM	19	25	26	62	96	123	152	176	272	336	435	164	1886
2	AI	12	12	17	12	11	24	25	12	36	39	69	40	309
3	3D printing	0	0	0	0	2	0	3	10	33	55	90	58	251
4	Machine learning	1	0	2	1	2	3	8	9	25	48	89	46	234
5	IoT	0	0	0	1	2	3	8	14	21	50	82	43	224
6	GIS	2	13	10	12	10	17	23	21	23	33	39	17	220
7	VR	5	7	9	6	12	9	8	7	22	35	53	26	199
8	Big data	0	0	0	0	1	4	9	19	24	42	62	32	193
9	Robotics	4	3	4	4	4	5	7	11	15	15	59	34	165
10	AR	5	2	5	7	8	5	6	4	12	31	32	17	134

BIM: BIM is developed to act as a powerful tool to support effective information sharing and communication among stakeholders in the construction industry in the whole life cycle of building projects. Meanwhile, BIM-based project delivery establishes a paradigm for enhancing project efficiency (Tang et al. 2019).

AI: AI refers to the ability of machines that mimic human intelligence to solve complicated and ill-defined problems intelligently and adaptively by using algorithms. To promote the real digital strategies in the construction industry, AI serves as the backbone to change the way a construction project performs (Pan and Zhang 2021).

3D printing: 3D printing (also known as additive manufacturing) is an advanced manufacturing process of joining materials to make solid objects automatically from 3D model data without any dies, fixtures and tooling (Duballet, Baverel and Dirrenberger 2017). This technology has become quite popular in industrial design, transportation, and aeronautics to create functional prototypes because of its efficiency and minimum material wastage.

Machine learning: Machine learning, a subset of AI, makes systems evolve as if they are learning, utilizing algorithms based on existing data to predict future behaviour. During construction projects, it supports the automation of decision making in processes, logistics and safety (Tixier et al. 2016).

IoT: IoT represents the interconnection of sensing and actuating devices to capture data and enable information sharing via a unified framework (Khanna and Kaur 2019). In the construction industry, IoT is able to connect BIM with physical devices for on-site control and monitoring, optimizing communication and logistics (Tang et al. 2019).

GIS: GIS is a digital platform to store, manage and analyze different types of data and present their spatial location in maps (Zagvozda et al. 2019). It can be applied for scoping and preliminary study, visualization, and maintenance purpose in construction projects.

VR: VR can generate scenes with a realistic appearance from computer systems with glasses or CAVE (cave automatic virtual environment). Currently, VR is commonly integrated with BIM to improve safety and quality management. It can also be used as a design tool to allow clients

and end-users to immerse themselves inside their future built asset.

Big data: Three main attributes (i.e., volume, variety and velocity), also known as 3V, are used to define big data. Construction data is well explained by big data since it is typically large, dynamic and heterogeneous. By using big data techniques and technologies, large volumes of information generated by the construction could be explored.

Robotics: The robotic technology can be grouped into four general categories in construction, namely, on-site automated vehicles, off-site prefabrication systems, exoskeletons, and drones and autonomous (Delgado et al. 2019). The robot could help with element cutting, structural reinforcement bending, welding and other tasks (Tavares et al. 2019).

AR: AR is used to integrate images of virtual objects into the real world. It could satisfy the goal of enhancing users' perception of virtual prototyping with real entities by inserting the virtually simulated prototypes into the real environment (Li et al. 2018).

In addition to the technologies presented in the table, there is a significant rising trend of investigating blockchain, cyber-physical systems (CPS) and digital twin in the research articles in the past four years (2017 to 2020), with an annual growth rate of 273%, 132% and 127%, respectively. Moreover, more than 32% of the reviewed articles come from six academic journals, including Automation in Construction, Journal of Construction Engineering and Management, Journal of Information Technology in Construction, Sustainability, Advanced Engineering Informatics and Engineering, Construction and Architectural Management.

Moreover, CNKI database was employed as the analysis object to investigate the research trend of the top ten technologies studied in China (as shown in Figure 2). Although the rankings of specific technologies are slightly different from Table 1, 90% of the technologies that appeared in Figure 2 are also included in Table 1, except for AR and UAV. UAV refers to small-scale remote-controlled aerial vehicles equipped with sensors and cameras. The application of UAV technology could improve safety planning and monitoring processes on construction site since it can access specifically inaccessible, hard-to-reach, or unsafe locations (Martinez, Gheisari and Alarcón 2020).

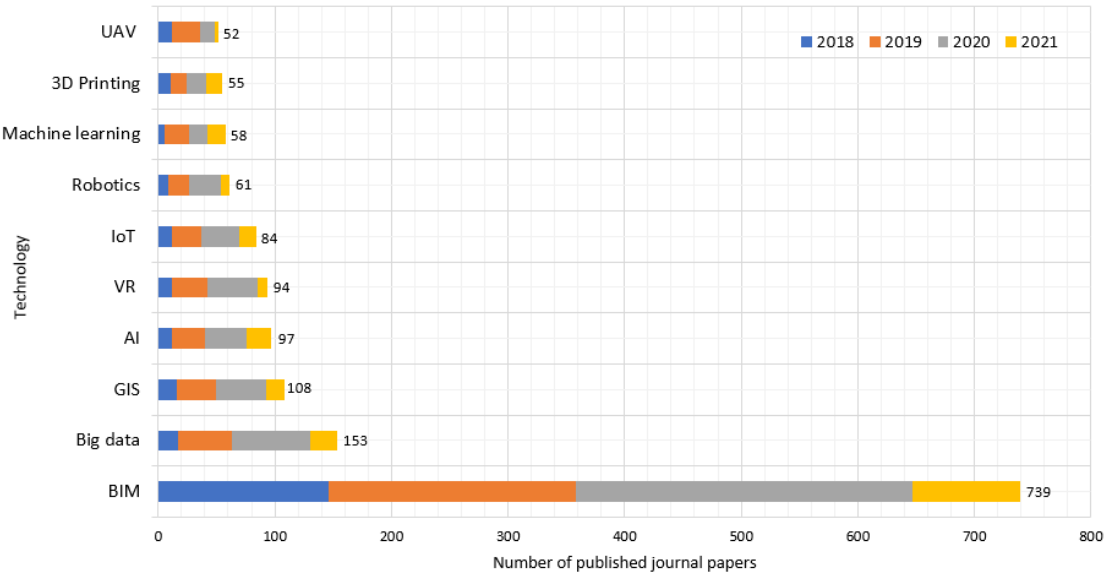

Figure 2 Frequency of occurrence for the top ten digital technologies (CNKI)

Based on the data extracted from these two databases, it can be observed that BIM has become

the core technology in the construction industry at the current stage, since BIM could improve the management process and integrate with other tools to enhance its functionality. For instance, with the integration of BIM and prefabrication, the field hospitals could be built ultra-rapidly to combat the COVID-19 pandemic (Luo et al. 2020).

Survey results and analysis

A total of 145 valid responses were generated to investigate the current application status of digital technologies. The respondents have at least three years of working experience in the AEC industry, including civil engineer (51%), construction/project manager (41%) and consultant (8%).

The RII results are presented in Table 2, showing the most used digital technologies. Three technologies have occurred in Table 1 and Figure 2, which are BIM, UAV and GIS. Mobile devices, Digital signature, Electronic Document Management (EDM) systems, Global Positioning System (GPS), 5G, Radio Frequency Identification (RFID) and Terrestrial Laser Scanning (TLS) are other representative technologies, which are briefly introduced below.

Table 2. RII analysis results of the top ten used technologies

Technology	Total respondents						
	1	2	3	4	5	RII	Rank
Mobile devices	5	27	43	38	32	0.690	1
BIM	9	43	55	20	18	0.593	2
Digital signature	19	42	42	12	30	0.589	3
EDM	20	42	39	23	21	0.577	4
UAV	14	48	43	22	18	0.575	5
GPS	10	59	41	15	20	0.567	6
GIS	15	57	38	16	19	0.554	7
5G	19	52	37	21	16	0.549	8
RFID	28	52	32	18	15	0.517	9
TLS	36	45	42	11	11	0.484	10

Note: 1: Very low level; 2: Low level; 3: Moderate level; 4: High level; 5: Very high level.

Mobile devices: They provide convenience and flexibility for construction tasks. The commonly adopted mobile devices contain smartphones, iPads, field tablets, laptops, and others.

Digital signature: Digital signature refers to digitally encrypted/decryption electronic signatures, including identities, time and date, and a password. The review and approval process of the submitted electronic documents could be accelerated by using it.

EDM systems: EDM systems enable all electronic documents to be stored, updated, and shared through a web server in a project (Guo, Jahren and Turkan 2018).

GPS: GPS provides services for positioning, navigation and timing (PNT). On construction projects, GPS could locate and track the position of workers and machines, to improve safety instruction (Tang et al. 2019).

5G: It is the fifth generation of wireless systems or mobile networks technology, with decreased latency for a larger number of connected devices and increased average bandwidth speed (Gupta et al. 2019).

RFID: RFID typically consists of three components, namely, RFID tags, RFID antennas and a host computer. It could be applied for tracking and identifying moving objects between different

positions.

TLS: TLS, also known as terrestrial or topographic LiDAR (light detection and ranging), is utilized to measure the distance from the device to the target and acquire 3D point cloud of the scanned objects, which can be applied for geometric quality assessment due to its high speed and accuracy (Rashidi et al. 2020).

It is reasonable that most trending technologies in research are not on this list (Table 2) since it takes time for people to learn the right skills to apply and use the technologies effectively and for industry enterprises to invest them.

An open question was raised to ask participants to recommend the promising digital technologies that should be invested in the AEC industry. Nine technologies have over 5% occurrence frequency (see Figure 3). Accordingly, BIM (21%) is the most recommended technology by participants, followed by 5G, UAV, Robotics, GPS, EDM, 3D printing, IoT and RFID.

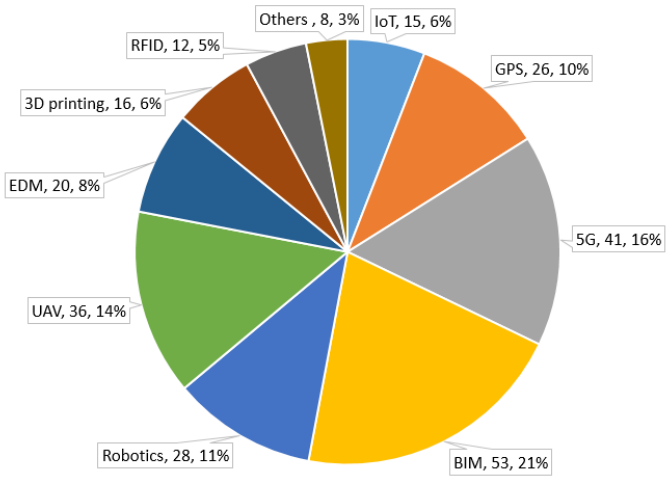

Figure 3 Recommendation of key technologies for investment

CONCLUSION AND RECOMMENDATION

Digital transformation is inevitable in the AEC industry. By using different digital technologies, greater efficiency, safety and productivity could be achieved for construction projects. Nevertheless, the rapid change and updating of technologies put tremendous pressure on stakeholders in terms of selecting and adopting the new technologies. This paper investigates the research and practical trends of digital technologies in the AEC industry, which could serve as the basis for organizations to determine their future direction and strategies associated with technology implementation.

In this study, multiple databases were utilized to identify 65 technologies applied in the AEC industry. Based on the Scopus database, the top ten technologies that have been mostly researched from 2010 to 2021 are presented, including BIM, AI, 3D Printing, Machine Learning, IoT, GIS, VR, Big Data, Robotics and AR. Meanwhile, the research trend of the technologies in China was explored by using the CNKI database. The top ten technologies investigated in Chinese academia are also presented and compared with the previous top ten list, where nine out of ten technologies appear in both of the lists. Overall, BIM is the technology that has been mostly studied in the field of civil engineering.

Based on the survey results, the most used technologies in the Chinese AEC industry are

Mobile devices, BIM, Digital signature, EDM, UAV, GPS, GIS, 5G, RFID and TLS. From the perspective of participants, BIM, 5G, UAV, Robotics, GPS, EDM, 3D printing, IoT and RFID are the promising technologies that should be invested in the AEC industry.

Finally, digitalization is not only about technologies, it is also about processes, organization and people. The successful implementation of new technologies could be affected by various factors from multiple perspectives such as socio-economic (e.g., governance mode), psychological (e.g., behavioural intention) and managerial (e.g., top-management support). In future work, research and development in some specific technologies are still needed and this paper has provided a clear direction of research trend. Once stakeholders have realized the full potential of digital technologies, the future AEC industry will be reshaped and brought into a construction 4.0 era.

REFERENCES

CCIA (China Construction Industry Association). (2021). Statistical Analysis of Construction Industry Development in 2020. <http://www.zgjzy.org.cn/> (accessed 5 May 2021).

Craveiroa, F., Duartec, J.P., Bartoloa, H. and Bartolod, P.J. (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. sustainable development, 4, p.6.

Delgado, J.M.D., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M. and Owolabi, H. (2019). "Robotics and automated systems in construction: Understanding industry-specific challenges for adoption." Journal of Building Engineering, 26, p.100868.

Duballet, R., Baverel, O. and Dirrenberger, J. (2017). "Classification of building systems for concrete 3D printing." Automation in Construction, 83, pp.247-258.

Guo, F., Jahren, C.T. and Turkan, Y. (2018). "Electronic Document Management Systems for the Transportation Construction Industry." International Journal of Construction Education and Research, 17(1), pp.52-67.

Gupta, R., Tanwar, S., Tyagi, S. and Kumar, N. (2019). "Tactile internet and its applications in 5g era: A comprehensive review." International Journal of Communication Systems, 32(14), p.e3981.

Khanna, A. and Kaur, S. (2019). "Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture." Computers and electronics in agriculture, 157, pp.218-231.

Levac, D., Colquhoun, H. and O'Brien, K.K. (2010). "Scoping studies: advancing the methodology." Implementation science, 5(1), pp.1-9.

Li, X., Yi, W., Chi, H.L., Wang, X. and Chan, A.P. (2018). "A critical review of virtual and augmented reality (VR/AR) applications in construction safety." Automation in Construction, 86, pp.150-162.

Luo, H., Liu, J., Li, C., Chen, K. and Zhang, M. (2020). "Ultra-rapid delivery of specialty field hospitals to combat COVID-19: Lessons learned from the Leishenshan Hospital project in Wuhan." Automation in Construction, 119, p.103345.

Martinez, J.G., Gheisari, M. and Alarcón, L.F. (2020). "UAV integration in current construction safety planning and monitoring processes: Case study of a high-rise building construction project in Chile." Journal of Management in Engineering, 36(3), p.05020005.

Metro, K., Harper, C. and Bogus, S.M. (2021). "Factors Affecting Workforce Resilience in Public Transportation Agencies." Journal of Management in Engineering, 37(4),

p.04021018.
National Bureau of Statistics. (2021). China National Economic and Social Development Statistics Bulletin 2020. <https://data.stats.gov.cn/> (accessed 5 May 2021).
Oesterreich, T.D. and Teuteberg, F. (2016). “Understanding the implications of digitization and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry.” Computers in industry, 83, pp.121-139.
Pan, Y. and Zhang, L. (2021). “Roles of artificial intelligence in construction engineering and management: A critical review and future trends.” Automation in Construction, 122, p.103517.
Pärn, E.A. and Edwards, D.J. (2017). “Conceptualizing the FinDD API plug-in: A study of BIM-FM integration.” Automation in Construction, 80, pp.11-21.
Rashidi, M., Mohammadi, M., Sadeghlou Kivi, S., Abdolvand, M.M., Truong-Hong, L. and Samali, B. (2020). “A decade of modern bridge monitoring using terrestrial laser scanning: Review and future directions.” Remote Sensing, 12(22), p.3796.
Sepasgozar, S.M., Davis, S.R., Li, H. and Luo, X. (2018). “Modeling the implementation process for new construction technologies: Thematic analysis based on Australian and US practices.” Journal of Management in Engineering, 34(3), p.05018005.
Tang, N., Hu, H., Xu, F. and Zhu, F. (2019). “Personalized safety instruction system for construction site based on internet technology.” Safety science, 116, pp.161-169.
Tang, S., Shelden, D.R., Eastman, C.M., Pishdad-Bozorgi, P. and Gao, X. (2019). “A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends.” Automation in Construction, 101, pp.127-139.
Tavares, P., Costa, C.M., Rocha, L., Malaca, P., Costa, P., Moreira, A.P., Sousa, A. and Veiga, G. (2019). “Collaborative welding system using BIM for robotic reprogramming and spatial augmented reality.” Automation in Construction, 106, p.102825.
Tixier, A.J.P., Hallowell, M.R., Rajagopalan, B. and Bowman, D. (2016). “Application of machine learning to construction injury prediction.” Automation in construction, 69, pp.102-114.
Zagvozda, M., Dimter, S., Moser, V. and Barišić, I. (2019). “Application of GIS technology in pavement management systems.” Građevinar, 71(04.), pp.297-304.
Zhao, X., Zuo, J., Wu, G. and Huang, C. (2019). “A bibliometric review of green building research 2000–2016.” Architectural Science Review, 62(1), pp.74-88.